

Microwave Limb Sounder (MLS)

Mass Fraction of Cloud Ice Data Description

1. Intent of This Document

1a) This document is intended for users who wish to compare satellite derived observations with climate model output in the context of the CMIP5/IPCC (or CMIP6) historical experiments. Users are not expected to be experts in satellite derived Earth system observational data. This document summarizes essential information needed for comparing this dataset to climate model output. References to additional information for expert users are provided at the end of this document.

This NASA dataset is provided as part of an experimental activity to increase the usability of NASA satellite observational data for the model and model analysis communities. This is not a standard NASA satellite instrument product. It may have been reprocessed, reformatted, or created solely for comparisons with the CMIP5 model. Community feedback to improve and validate the dataset for modeling usage is appreciated. Email comments to HQ-CLIMATE-OBS@mail.nasa.gov.

Dataset File Name (as it appears on the ESG):

Primary dataset:

cli_MLS_L3_v4.2_200408-201512.nc

1b) Technical point of contact for this dataset:

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2. Data Field

The MLS mass fraction of cloud ice together with its ancillary data is provided in a single file as noted in section 1a. The variable cli represents average cloud ice water content (IWC) observed by MLS in terms of mass fraction for each bin of size 2 deg (latitude) × 2.5 deg (longitude). The variable cliNobs details the number of satellite observations in each bin. The variable cliStderr is the standard error within each bin.

Table 1, MLS mass fraction of cloud ice data field summary

CF variable name, units:	cli, unity.
Spatial resolution	The vertical resolution is determined by the seven levels used by the MLS retrieval (215 hPa, 178hPa, 147 hPa, 121hPa, 100 hPa, and 83 hPa) together with two additional CMIP5 mandatory levels (200 hPa, 150 hPa). The horizontal resolution is 2 degrees of latitude by 2.5 degrees of longitude.
Temporal resolution and extent:	The product is formed with monthly averages covering the period from August 2004 through Dec 2015.
Coverage:	Global, except latitudes higher than 82 degree.

Note: MLS provides data in the upper troposphere with pressure lower than 300 hPa. It is recommended to use MLS cloud ice data [1] for those pressures (less than or equal to 215 hPa).

3. Data Origin

These data are derived from the standard MLS retrieved data (version v4.2 that can be obtained from the Goddard Earth Science (GES) Data and Information Services Center (DISC) data access[2].

The MLS IWC is retrieved from cloud-induced radiances (T_{CIR}) of the 240-GHz window channel in a separate processing step after the atmospheric state (Temperature and tangent pressure) and important gaseous species (H_2O , O_3 , HNO_3 , etc.) have been finalized in the retrieval processing. The derived T_{CIR} are binned onto the standard vertical (12 surfaces per decade change in pressure) grids, and converted to IWC using the modeled T_{CIR} -IWC relations[3] [4]. The standard IWC profile has a useful vertical range between 215-83 hPa. IWC measurements beyond the value ranges in Table 2 are regarded currently as giving only qualitative information on cloud ice.

In generating the level 3 data, one month of these data was read in and screened according to the MLS data quality document [5] [6]. It was then binned into the latitude-longitude grid with grid box size 2 deg \times 2.5 deg (latitude \times longitude) and the sample mean within each grid box gives the corresponding value of IWC. For each grid point, the data was linearly interpolated to the Obs4MIPs required pressure levels surfaces using the logarithm of the pressure. The standard error for the interpolated value is the larger standard error of the two levels involved. We include both the original retrieval pressure levels and the Obs4MIPs required levels in the data product (see Table 1).

4. Validation

Precision and systematic errors of IWC are estimated based on errors in estimated T_{CIR} and the uncertainties in the T_{CIR} -IWC relation [5]. Uncertainties of the derived 240 GHz T_{CIR} , attributed to either the measured [7] or the modeled [8] radiance errors, are often dominated by the model errors. Figure 1 plots the percentage error of T_{CIR} and IWC as a function of IWC. The range where a single IWC measurement is quantitatively useful is defined here as IWC percentage error $< 100\%$. At small values, the measurement noise is the determining factor. Each IWC measurement must be larger than the 3σ noise to be statistically significant. At large IWC values, the T_{CIR} saturation causes great uncertainty in the retrieved IWC as a small T_{CIR} error can correspond to a large IWC error. Large IWC values, though associated with an uncertainty $> 100\%$, are still qualitatively useful. At 261 hPa the IWC measurements are only qualitatively useful because the IWC relative error exceeds 100% at $IWC > 30 \text{ mg/m}^3$ while $IWC < 12 \text{ mg/m}^3$ are mostly noise. Hence the recommended useful range of IWC is for pressure levels within 215-83 hPa.

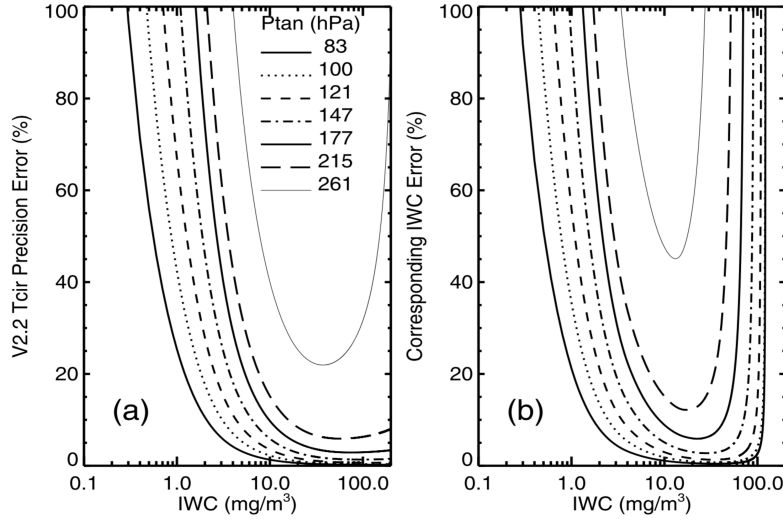


Figure 1 (a) Estimated T_{CIR} precision as a function of IWC in percentage for different tangent pressures. (b) Estimated IWC precision as a function of IWC in percentage.

Table 2 summarizes typical single-measurement precisions and useful ranges of the V4.2 IWC for different pressure levels. The user needs to obtain a more accurate precision estimate using a screening method described in reference [5] on a daily basis. The V4.2 IWC precision increases with pressure, which is consistent with the value expected from the T_{CIR} error in Figure 1.

Table 2, Estimated MLS IWC Precision and Useful Range

Pressure / hPa	Resolution ^a / km	Typical precision ^b / mg/m^3	Accuracy ^c / mg/m^3		Valid IWC range ^d / mg/m^3
			<10 mg/m^3	>10 mg/m^3	
p<70		Unsuitable for scientific use			
83	200×7×5	0.07	100%	—	0.02 – 50
100	200×7×5	0.10	100%	150%	0.02 – 50
121	250×7×4	0.15	100%	100%	0.04 – 50
147	300×7×4	0.25 – 0.35	100%	100%	0.1 – 50
177	300×7×4	0.5 – 1.0	150%	100%	0.3 – 50
215	300×7×4	1.2 – 2.1	300%	100%	0.6 – 50
p>260		Unsuitable for scientific use			

^aThe along-track, cross-track and vertical extent, respectively of the atmospheric volume sampled by an individual MLS measurement

^bThese are typical 1 standard deviation precisions.

^cEstimated from comparisons with CloudSat and CALIPSO.

^dThese are the ranges where the stated precision, accuracy and resolution are applied. In this range MLS measurements can be quantitatively interpreted as the average IWC for the volume sampled. IWC values above this range, currently giving qualitative information on cloud ice, require further validation for quantitative interpretation.

Systematic uncertainties of the V4.2 IWC are summarized in Table 2. Although cloud inhomogeneity can cause large uncertainties on individual IWC measurements, this error is mostly random and can be reduced by averaging the data [9]. The largest systematic uncertainty in the MLS IWC retrieval is from the particle size distribution (PSD) assumptions used in the cloudy- sky RT models. The MH97 parameterization used by the MLS IWC retrieval may not be applicable to deep convective cores nor to mid-latitude clouds. The modeled T_{CIR} -IWC relations from different PSDs can differ systematically by as much as 100% or more. Currently, we do not have a PSD parameterization that can represent global ice cloud properties accurately. In situ observations of PSDs remain very sparse and incomplete, resulting in poorly constrained microphysical assumptions used in MLS IWC retrievals. More work is needed to improve PSD parameterization and statistical properties of global ice clouds.

MLS V4.2 IWC is similar to the MLS V2.2 product described and validated in Wu et al. [5]. A revised validation paper for IWC is thus not planned in the near future and users are encouraged to read Wu et al. [5] for more information. Comparisons between V4.2 MLS and CloudSat IWC showed good agreement with PDF differences <50% for the IWC ranges specified in Table 2. Comparisons with AIRS, OMI and MODIS suggest that MLS cloud tops are slightly higher by ~ 1 km than the correlative data in general.

There is a known artifact related to the way, in which the last few profiles of the day (close to mid-night) is handled by the MLS retrieval software., This artifact results in an “orbit-like” feature of 0.01-0.05 mg/m^3 positive bias (see the 11-year climatology displayed in Figure 2.). which can only be seen clearly when we average down random errors [9].

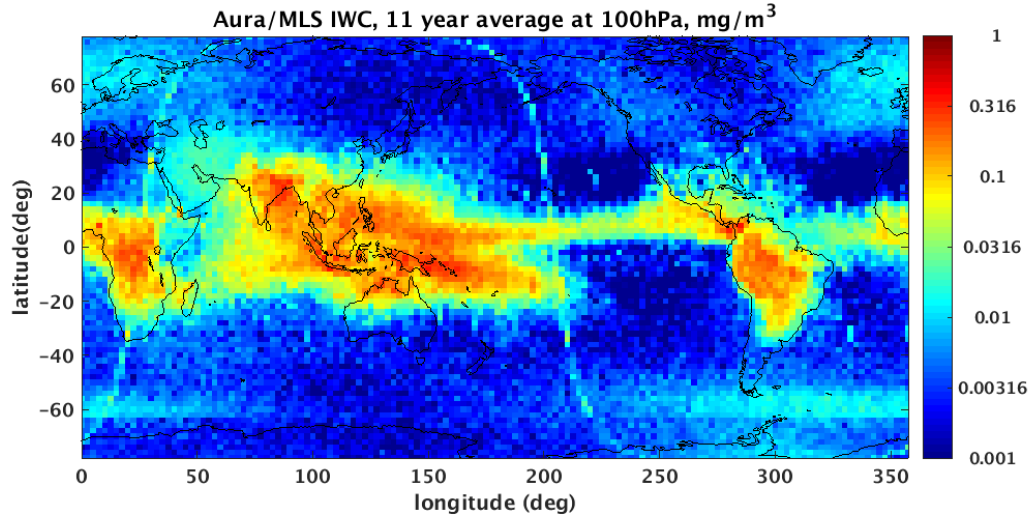


Figure 2, A systematic “orbit-like” bias in the MLS retrieval.

5. Consideration for Model-Observation Comparisons

If judicious model-observation comparisons are to be made, users should be aware of several aspects that distinguish these data products from model outputs.

5.1 Time Sampling Bias

Because MLS is on board the Aura satellite in a sun-synchronous polar orbit, it samples at the two fixed local solar times at each location (e.g. 1:45 AM and 1:45 PM at the equator) and does not resolve the diurnal cycle[10]. MLS observations at a given latitude on either the ascending (north-going) or descending (south-going) portions of the orbit have approximately (to within several minutes) the same local solar time throughout the mission, as indicated in Figure 3 [11]. In contrast, typical model monthly averaged outputs contain the averaged values over every point in a time series of data with a fixed time interval (e.g. every 6 hours). For many constituents in the upper troposphere, this difference is not likely to be an issue. However, for regions influenced by deep convection and its modulation of the diurnal cycle (e.g. tropical land masses), this time sampling bias should be considered.

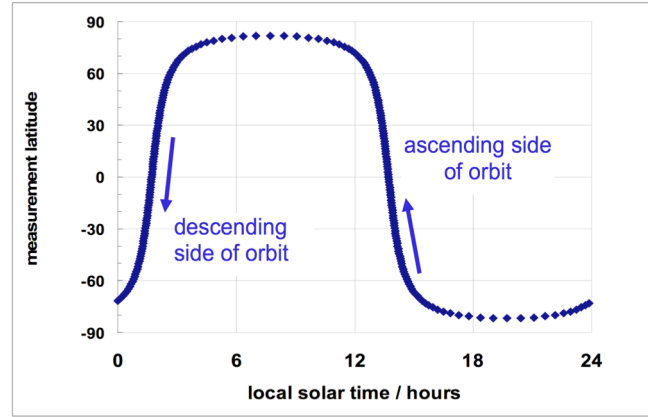


Figure 3: Local solar time when MLS observes a given latitude on the Aura sun-synchronous polar orbit.

5.2 Inhomogeneous Sampling

Because the monthly averaged value in this MLS data product is an average over observational data available in a given latitude-longitude box, the number of samples used for averaging varies with the location of the box. Due to the geometry of the Aura sun-synchronous polar orbit, there are no observations above latitude 82° and there are more observations near the boundary (70°-82°) than the rest of the area. Figure 4 shows the distribution of the typical number of samples used for the monthly averaged product.

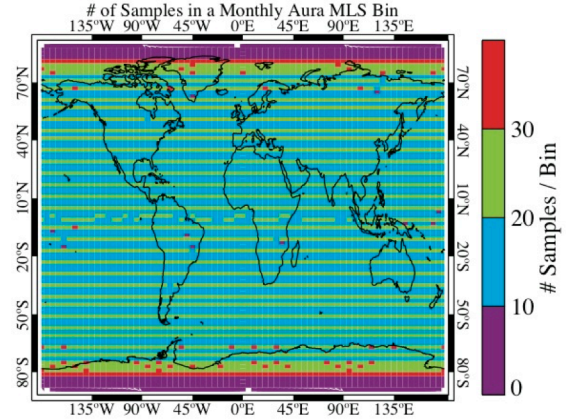


Figure 4: Distribution of the typical number of samples used for the monthly averaged MLS

5.3 Anisotropic and Inhomogeneous Resolution

While a typical model output has a fixed horizontal resolution, MLS observations have anisotropic and inhomogeneous resolutions in a horizontal direction due to its viewing geometry and radiometric response. MLS horizontal resolutions for IWC measurements range from 4 to 7 km across the orbit track and 200 to 300 km along the orbit track (see Table 2 for details). Therefore, MLS observations have elongated shape 'footprints'. The sample data used in the monthly averaging are the collection of observations whose footprint centers are located in a given grid box. This means that the averaged value for a given grid box can be influenced by the state of the atmosphere in neighboring grid boxes, due to the mismatch between the gridded box resolution and the MLS native observation resolution.

5.4 Vertical levels

MLS IWC data product included the union of CMIP5 mandatory pressure levels 100hPa, 150hPa, and 200hPa and the original MLS retrieval levels [83, 100, 121, 147, 178, 215] hPa. The cli data from model are at the model levels (typically hybrid sigma coordinate levels, see CMIP5 meta data requirement [12] for details). Resampling model data to MLS retrieval level will enable a direct comparison without introducing extra interpolation errors from regridding both model and observation data to the mandatory pressure levels. Therefore, the inclusion of MLS retrieval levels here provides an option for comparing model and observation at a higher fidelity.

5. Instrument Overview

[The Earth Observing System \(EOS\) Microwave Limb Sounder \(MLS\)](#) is a satellite instrument that provides observations of atmospheric composition, temperature, moisture, and cloud ice profiles in the upper troposphere and lower stratosphere. The MLS measurements are designed to (1) track stability of the stratospheric temperature layer, (2) help improve predictions of climate change and variability, and (3) help improve understanding of global air quality.

MLS is one of four instruments on the [NASA's EOS Aura satellite](#), launched on July 15th 2004. Aura is in a near-polar 705 km altitude sun-synchronous orbit. As Earth rotates underneath it, the Aura orbit stays fixed relative to the sun and gives daily global coverage at a fixed local times for each latitude on the ascending and descending side of the orbit, with observations in the tropics and mid-latitudes made around 1:45am (descending) and 1:45pm (ascending), and ~13 orbits per day. Aura is part of NASA's A-train group of Earth observing satellites. These satellites fly in formation with the different satellites making measurements within a short time of each other as shown in Figure 5.

MLS obtains remote measurements of atmospheric parameter profiles by measuring millimeter and sub-millimeter-wavelength thermal emission with seven microwave receivers using a limb viewing geometry. MLS views forward along the Aura satellite flight direction and scanning its view from the ground to ~90 km altitude. The limb viewing

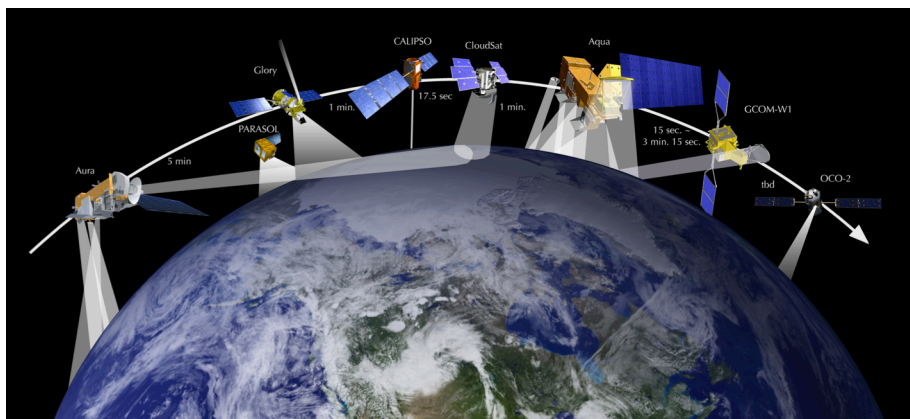


Figure 5: NASA's A-train group of Earth observing satellites.

geometry of MLS is shown in Figure 5. Thanks to the limb viewing geometry, MLS provides the relatively good vertical resolution for composition observations in the upper troposphere and lower stratosphere, compared to nadir sounders. At present, the MLS

record is more than 11 years long, the instrument remains in good health and we expect several years of continued operation.

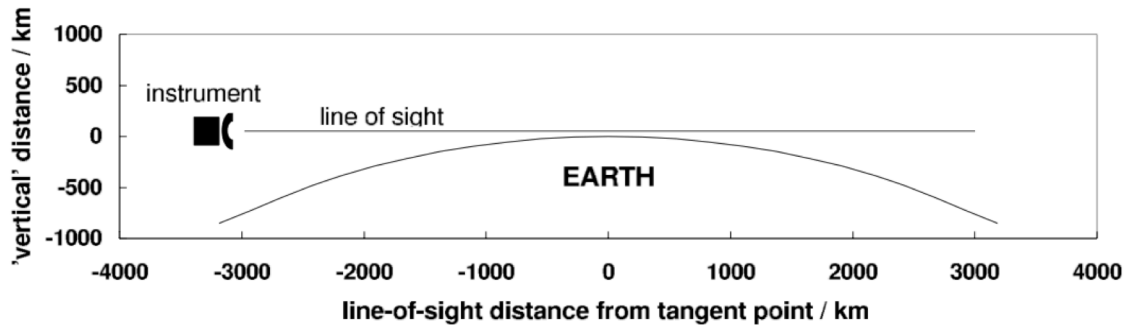


Figure 6: MLS viewing geometry. The geometry is drawn to scale with an instrument in 705 km altitude orbit of the Aura satellite and the line of sight having 50 km tangent height. The orbit plane for EOS MLS is the plane of the paper [13]

7. References

- [1] Austin, R. T., A. J. Heymsfield, and G. Stephens (2009), Retrieval of ice cloud microphysical parameters using the CloudSat millimeter-wave radar and temperature, *J. Geophys. Res.*, 114, D00A23, doi:10.1029/ 2008JD010049.
- [2] <http://disc.sci.gsfc.nasa.gov/Aura/data-holdings/MLS/index.shtml>
- [3] Wu, D.L., & Jiang, J.H., EOS MLS algorithm theoretical basis for cloud measurements, JPL Document D-19299, 2004.
- [4] Wu, D.L., J.H. Jiang, and C.P. Davis, "EOS MLS cloud ice measurements and cloudy-sky radiative transfer model," *IEEE Trans. Geosci. Remote Sensing* 44, no. 5, 1156-1165, doi:10.1109/TGRS.2006.869994, May 2006.
- [5] Wu, D. L., J. H. Jiang, W. G. Read, R. T. Austin, C. P. Davis, A. Lambert, G. L. Stephens, D. G. Vane, and J. W. Waters (2008), Validation of the Aura MLS cloud ice water content measurements, *J. Geophys. Res.*, 113, D15S10, doi:10.1029/ 2007JD008931.
- [6] EOS Aura Microwave Limb Sounder Version 2.2 Level 2 data quality and description document, [v2-2_data_quality_document.pdf](#). See Table 3.12
- [7] Jarnot, R. F., V. S. Perun, and M. J. Schwartz (2006), Radiometric and spectral performance and calibration of the GHz bands of EOS MLS, *IEEE Trans. Geosci. Remote Sens.*, 44(5), 1131 – 1143, doi:10.1109/ TGRS.2005.863714.
- [8] Read, W. G., Z. Shippony, M. J. Schwartz, N. J. Livesey, and W. V. Snyder (2006), The clear-sky unpolarized forward model for the EOS Microwave Limb Sounder (MLS), *IEEE Trans. Geosci. Remote Sens.*, 44(5), 1367– 1379, doi:10.1109/TGRS.2006.873233.
- [9] The monthly averaged data described in this document have the same accuracy as the MLS retrieval but the precision is improved by the factor of $1/\sqrt{N}$ due to the averaging over independent samples, where N is the number of the samples. As shown in Figure 4, the number of samples N fluctuates around 16 (with a standard deviation of 5.4) between 72 degrees of latitude North and 72 degrees of latitude South.
- [10] EOS MLS Level 3 Algorithm Theoretical Basis, [eos_l3_atbd.pdf](#), p9, p30.
- [11] An Overview of the EOS MLS Experiment, [eos_overview_atbd.pdf](#), p38.
- [12] http://cmip-pcmdi.llnl.gov/cmip5/docs/CMIP5_output_metadata_requirements.pdf
- [13] An Overview of the EOS MLS Experiment, [eos_overview_atbd.pdf](#), p6.

8. Revision History

Rev 0 - 4/28/16 -